Combining Acoustic, In-Situ, and Remotely-Sensed Data with Regional Ocean Models in the East China and Philippine Seas

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LONG-TERM GOALS

The long-term scientific objective of the Quantifying, Predicting, and Exploiting (QPE) Uncertainty Directed Research Initiative (DRI) is to improve the assessment of uncertainty in observations and predictions of sound propagation in littoral regions. The objectives of this research are to understand and exploit the effects of the ocean state on acoustic propagation and detection.

OBJECTIVES

This work will contribute to the goals through global and regional physical ocean modeling and data assimilation. The modeling includes both model comparisons with observations, evaluating model error, and forecast and predictability studies to see the growth of uncertainty in time and space and the influences of the past ocean state on the acoustic propagation conditions on the shelf north of Taiwan.

APPROACH

The QPE DRI is a coordinated effort in which many types of measurements have been collected over the continental shelf to the north of Taiwan. The field results will be used to help characterize the rapidly varying physical environment in comparison to the models and to study acoustic propagation and scattering in the region.

Our modeling and analysis technical approach uses a variety of models to build upon and extend observational findings by simulating the time-varying circulation and stratification of the region and placing it in the larger-scale context provided by global ocean models. The comparative skills and

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dynamics of the simulations provide an understanding of predictability constraints. We use the Frechet derivative (adjoint) of a regional ocean model to explore the sensitivity of critical environmental features of the shelf region to the ocean in the region, to forcing, and to boundary conditions. Also in the longer term, acoustic remote sensing data, together with data from direct measurements and satellite remote sensing, will be assimilated into a regional ocean model to estimate the evolving ocean state using the adjoint technique. Fine-resolution global ocean general circulation models provide an understanding of non-local oceanic forcing as well as additional realizations of the time-varying flow in the domain under investigation.

Initially we configured a fine-resolution (1/12°) regional general circulation ocean model, using the MIT general circulation model (MITgcm), for a region encompassing Taiwan. This model can provide lateral boundary conditions to a smaller regional model to the northeast of Taiwan being run by Lermusiaux (MIT). Initial and lateral boundary conditions for our model are obtained from a global 1/12° Hybrid Coordinate Ocean Model (HYCOM) assimilation product. The choice of lateral boundary conditions is central to the issue of uncertainty. HYCOM is forced with daily Navy Operational Global Atmospheric Prediction System (NOGAPS) fluxes and uses the Navy Coupled Ocean Data Assimilation (NCODA) to assimilate data. First we needed to determine the fidelity of the output in the larger northwest Pacific region by considering the representation of those processes that will be felt at the boundaries of our regional model. These are primarily westward propagating mesoscale eddies. We also needed to consider the variability of the surrounding waters such as the annual cycle, mean flows, stratification and mixed layer depths.

In preparation for the regional modeling/data assimilative effort we gathered both in-situ and remotely sensed data for the larger northwest Pacific region. These data include temperature and salinity vertical profiles from Argo floats, Expendable Bathythermograph (XBT) temperature data, velocity and temperature at 15 m from surface drifting buoys, sea surface height from altimetry, and sea surface temperatures. The data were quality controlled and manipulated as appropriate for insertion in the data assimilation scheme.

Extended multi-year time series (up to a decade in one case) of fields from both the data assimilative and forward HYCOM simulations and the 1/10° Parallel Ocean Program (POP) were extracted for the western Pacific region. Fidelity assessments of the models' mean and variability in this region were conducted. As well, comparisons between QPE data collected during the 2009 field campaign and consistent data assimilative HYCOM output were performed.

WORK COMPLETED

In the past year, the project focus has been on detailed comparisons of the models with observations and examination of the phenomenology of the key oceanographic processes: the Cold Dome and Kuroshio intrusions onto the shelf northwest of Taiwan. Using HYCOM output as initial and boundary conditions, two sets of regional MITgcm runs have been conducted, one in a large region that extends from 116°E to 140°E and from 17°N to 27°N, and the other in a domain one quarter the size, which extends from 116°E to 128.5°E and from 22°N to 27°N. The larger domain has been run at 1/12° and 1/24° degree, while the small domain has been run at 1/24° degree. Both setups used 50 layers in the vertical, including 5m spacing near the surface.

The simulations were evaluated based on the realism of environmental features seen as keys for the observational program. The Kuroshio path was compared to float observations by Centurioni and Niiler, including both the Luzon Strait Loop Current and the Kuroshio surface water intrusions onto

the shelf northwest of Taiwan. The similarity of the "Cold Dome" feature in the model to historical observations was also examined.

We have continued to study the sensitivity of the Kuroshio crossing of the Luzon Strait to model bathymetry. Several new bathymetry products have been tried, with significant effects on the path of the Kuroshio. This points up an important source of uncertainty in the modeling of the Kuroshio that needs further examination. Sensitivities were previously examined by Metzger and Hurlburt (Geophys. Res. Let. 2001) in the NLOM model.

Both larger and smaller domain runs have been extended to cover from 2004 to 2010, using NOGAPS and QSCAT winds with NCEP fluxes.

The forward runs showed realistic Kuroshio position, including intrusions onto the shelf, and had generally good cold dome structure. Cold features were formed both by interaction of the Kuroshio with the topography and by strong wind forcing on the shelf. The cold features were also influenced by the Taiwan Strait flow and its seasonal variability. The cold dome timescale was seen to be approximately ten days. The upwelling of high-salinity Kuroshio water was seen in the center of the cyclonic eddy forming the cold dome in some cases.

Low and high Kuroshio Current transport events through the East Taiwan Channel or sea level height events offshore of Taiwan were identified in all the global ocean simulations. Lagrangian trajectories were initialized in the Kuroshio to the east of Taiwan at 22° and 24°N during these events. Composite velocity fields were constructed for the high and low events and trajectories were released in these composite flows. The spread of behavior was examined from individual tracks as well as differences arising from the inclusion of data assimilation in HYCOM. Vertical sections of the shelf/slope stratification to the north of Taiwan were examined during these events as well as the circulation and thermohaline structure of the East China Sea. Additionally, SeaSoar data collected by the R/V Ocean Researcher 1 from 08/25/2009 through 09/10/2009 as part of the QPE field campaign were compared with consistently sampled data assimilative HYCOM output.

RESULTS

The model runs have agreed in a statistical sense with the hypothesis that the presence of cold (cyclonic) eddies to the east of Taiwan lead to reduced Kuroshio transport and increased probability of intrusions of surface water (and drifters) onto the shelf northwest of Taiwan. The 1/24 resolution MITgcm runs have shown realistic Cold Dome statistics, based on comparison to historical Taiwanese maps and SSH observations. The MITgcm improves on HYCOM in these respects. Further adjoint model runs have shown the strong nonlinearity of the region, limiting the time range of validity of the linearized gradients, but highlighting the interesting linear predictability that comes from the coherent eddy features propagating from the east.

IMPACT/APPLICATIONS

This study will lead to the improvement of the assessment of uncertainty in observations and predictions of sound propagation in littoral regions.

TRANSITIONS

Methodology and data results can be made available to Navy scientists.

RELATED PROJECTS

The work described here is in collaboration with Professor Peter Niiler at SIO and Dr Pierre Lermusiaux at MIT.